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Simulation of Working No-load Induction Machine with Assigned Electrical Parameters in Adapted File MATLAB

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Authors' contributions

This work was carried out in collaboration between all authors. Author SB designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors ZB and NM managed the analyses of the study. Author BJ managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The paper dealing with specific type of no-load induction machine are largely concerned with the conventional design. In each case, however, there is a other way on the presentation working principle and arrangement of the better commonly used modification. The aim of this paper is to develop a new adapted mathematical model and the simulation of asynchronous motor working. As basic resistance values for which a comparison is made of the results of calculation adopted by the resistances of the equivalent circuit of asynchronous motors with the cage and wound rotor, calculated in Catalog ``Sever Subotica``.
Suggested mathematical model can be used in the analysis of machine's work, as well as for synthesis control, and from the model itself complex algorithms for electrical machines control, vector control and momentum control can be developed.

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1. INTRODUCTION

In order to conduct the analysis of asynchronous motors and the influence on short circuit current, it is necessary to know the parameters of the equivalent circuit. References [1], and the recommendation [2], describe the methods for the determination of circuit parameters. This is the simple method for presentation of equivalent circuit and simulation of working of induction machine. This paper analyzes the method for determination of equivalent circuit parameters, as well as the development of the method which is suitable and accurate for simulation of induction motor working characteristics [3,4].

2. DETERMINATION OF PARMETRES OF ASYNCHRONOUS MOTOR EQUIVALENT CIRCUIT

Determined parameters are observed on the example of asynchronous motors with squirrel-cage rotor: 1.ZK160 L-4 и 1.ZKI 315 M-6. From electromagnetic calculations [5], base values were obtained for both motors (Table 1), and the values of asynchronous machines resistance were also determined (parameters of equivalent circuit, Table 2).

Equivalent circuits are shown in Picture 1. In Table 1 data are taken from [6,7], while in Table 2 there are the results of calculation for base work regime and values of sliding: ZK 160 L-4, $s_n = 0.024$ and ZKI 315 M-6: $s_n = 0.0345$.

Errors in calculation (deviations) can be determined from the difference between calculation values *A* and base values A_p (where, index 'p' stands for projecting), determined in [8] and shown in Table 2 by using the following formula:

$$\Delta A\% = [(A - A_p) / A_p] \cdot 100 \tag{1}$$

If the recommendation from [1], are used to determine the equivalent circuit parameters R_1, X_1, R'_2, X'_2, R_0, X_0, σ_1 of asynchronous machine should be calculated by using formulas shown in Table 3. In this table, position 15 has been added by the authors of this paper with the aim of more convenient display of materials. During the calculation [9,10,11] all the parameters of the equivalent circuit for 1. ZK 160L-4, except $R`_2$ и X_0, are determined with inadmissibly large errors in comparison to base values. This is why a logical question arises: why are the parameters determined in this way when the short-circuits current is calculated, or the equipment in the stations is chosen despite the differences in values of parameters determined following Table 3, and according to [1].

Calculated results are in accordance with the examples in which the impedance Z_e and Z_p are used (rows 2 and 15 of Table 3). In [1] it is mentioned that formulas applied to Table 3 are used for determination of all parameters present in equivalent T-circuit of asynchronous motor shown in Picture 1.a.

From Table 3, according to the values of parameters R_1, X_1, R'_2, X'_2, R_0, X_0, σ_1 determined from Table 3 form, it can be observed that the working characteristics cannot be calculated sufficient precision. In this paper we have obtained form shown in Table 4, using improved method and G- circuit, Picture 1.b.

The features of methods and forms are following: Expressions in rows 10-14 of Table 4 are equivalent to formulas taken from [1,6].

Table 1. Base values of overloading ability of machine ν and starting current factors $p = I_1 / I_n$ 1. ZK 160 L-4 и 2. ZKI 315 M-6, obtained from catalogue [7]

Mechanical protection: IP 54			μ [%]	cosφ$_n$	I_n [A]	M_n [Nm]	I_1/I_n	M_1/M_n	ν	Voltage: V1=400V, 50Hz	
Type of the motor	P_n [kW]	n_n [min^{-1}]								J [kgm^2]	Mass [kg]
ZK 160 L-4, n_s=1500	15	1440	88	0.82	30	99.5	6.2	3	2.89	0.073	118
ZK 315 M-4, n_s=1000	132	988	94.5	0.87	235	1276	7	1.8	1.67	6.6	1140

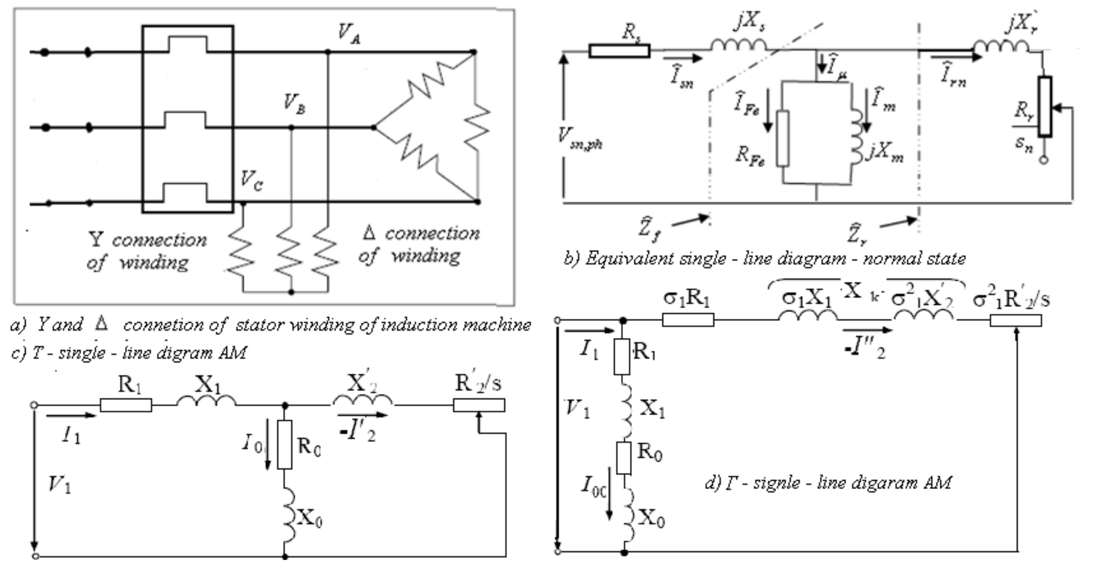
Expressions in rows 11, 12, and 13 from Table 4 are equivalent to rows 7, 8 and 9 from Table 3. The remaining expressions in Table 4 are obtained immediately from Pictures 1.a or 1.b and general theory [12-14]. In calculation, apart from following Table 4, data from machine's documents were used as a source (in this case 'Sever' Subotica machine).

Table 2. Base value of parameters of the equivalent circuit 1. 1.ZK 160L-4 and 2. 1.ZKI 315M-6

Mechanical protection: IP 54			Parameters of equivalent scheme V1=400 V , 50 Hz						
Type of the motor	R_1	$R_2^{'}$	X_1	$X_2^{'}$	R_0	X_0	σ_1	$\sum P$	s_n
ZK 160 L-4 $n_s = 1500$	0,355	0,186	0,53	0,912	1,47	17.24	1,025	1812,5	0,024
ZKI 315 M-6 $n_s = 1000$	0,072	988	0,35	0,47	0,349	1276	1,029	12984,0	0,0345

Table 3. Formula for the calculation of parameters according to [1], and the calculation of determined values of the asynchronous machine parameters

No.	Calculated value	Unit	ZK 160-L4	ZK 160-L4 fault, Δ A%
1	$I_n = P_n / (q_1 U_1 \eta_n \cos\varphi_n)$	A	30	
2	$Z_e = U_1 / I_n$	Ω	7,707	
3	$R_{1*} = s_n \% / 100$		0.024	
4	$R_1 = R_{1*} Z_e$	Ω	0,185	-47,6%
5	$\sigma_1 = \sqrt{(1 - s_n) p * / (2 \nu \cos \varphi_n)}$		1,14	11,5%
5.a	$\sin\varphi_n = \sqrt{1 - \cos^2 \varphi_n}$		0,572	
6	$X_0 = 1 / [\sigma_1 (\sin\varphi_n - \cos\varphi_n) / (\nu + \sqrt{\nu^2 - 1}))]$		3,01	
7	$X_0 = X_{0*} Z_e$	Ω	16,59	-7,3%
8	$X_1 = (\sigma_1 - 1) X_0$	Ω	3,60	431%
9	$X_{1*} = X_1 / Z_e$		0,465	
10	$X_{2*}^{'} = (1 - s_n) / (2\sigma_1^2 \nu \cos\varphi_n) - \frac{X_{1*}}{\sigma_1}$		-0,246	Has no physical significance
11	$X_2^{'} = X_{2*}^{'} Z_e$	Ω	-1.903	Has no physical significance
12	$R_{2*}^{'} = s_n (1 - s_n)(\nu + \sqrt{\nu^2 - 1}) / (2\sigma_1^2 \nu \cos\varphi_n)$		0,0116	
13	$R_2^{'} = R_{2*}^{'} Z_e$	Ω	0,0897	2,7%
14	$R_0 \approx 0$ allowed according to recommendation from [1],	Ω	0	
15	$Z_p = U_1 / (p^* I_n)$	Ω	1.248	



Picture 1. a) The connection of induction machine; b) The equivalent single line diagram of machine – normal state and the equivalent diagram of asynchronous machine; c) T- circuit; d) G- circuit

Table 4. Suggested form for calculation of parameters of motors 1.ZK 160 L-4 and 2. 1.ZKI 315 M-6 whose base values were obtained from the catalogue [7]

Calculated value	ZK 160-L4, Value A	ZK 135-M6, Value A
$p = 60 f_1 / n_1$	2	3
$k_E \approx 0{,}985 - 0{,}005\,p$	0,975	0,97
$\sigma_1 = 1 / k_E$	1.025	1,03
$I_n = P_n / (q_1 U_1 \eta_n \cos\varphi_n)$	29,9	231,6
$Z_e = U_1 / I_n$	7.7	0,985
$I^{`}_{2n} = (0{,}2 + 0{,}8 \cos\varphi_n) I_n$	25,68	207,5
$I''_{2n} = I_n / \sigma_1$	29,15	224,85
$Z''_{2n} = U_1 / I''_{2n}$	7,96	1,032
$\sin\varphi_n = \sqrt{1 - \cos^2\varphi_n}$	0,5723	0,493
$A = \sigma_1 \sin\varphi_n$	0,586	0,508
$B = \sigma_1 \cos\varphi_n$	0,84	0,896
$C = v + \sqrt{v^2 - 1}$ v=2.89 //1.87	4,98/5,60	3,45
$X_{0*} = 1 / (A - B / C)$	2,26	13,63
$X_0 = X_{0*} Z_e$	15,8	13.62
$L_m = L_0 = X_0 / 2\pi f$	0,04	0.011
$X_1 = (\sigma_1 - 1) X_0$	0,39	0,4086
$L_1 = X_1 / 2\pi f$	1.21e-3	0.344e-3
$X_{1*} = X_1 / Z_e$	0,049	0,109

Calculated value	ZK 160-L4, Value A	ZK 135-M6, Value A
$X'_{2*} = (1-s_n)/(2\sigma_1^2 v \cos\varphi_n) - X_{1*}/\sigma_1$	0,147	0.165
$X'_2 = X'_{2*} Z_e$	1,132	0,164
$L'_2 = X'_2 / 2\pi f$	3.6e-3	0.524e-3
$X''_k = \sigma_1 X_1 + \sigma_1^2 X'_2$	1,55	0,285
$R'_2 = s_n (U_1 / I_n) = s_n Z_e$	0,1856	0,0908
$R_1 = (1/\sigma_1)(\sqrt{Z''^2_{2n} - X''^2_k} - \sigma_1^2 R'_2 / s_n)$	0,282	0,0247
$I_{00} \approx U_1 / X_0$	7,731	28,05
$P_{1n} = P_n / \eta_n$	16782,51	144427
$P_{dop} = 0{,}005 P_{1n}$	83,91	1112,38
$P_{meh} = 0{,}007 P_{1n}$	117,478	1010,9
$P_{meh.r.n} = P_n + P_{dop} + P_{meh}$	15171,39	138958,36
$P_{em.n} = (1-s_n) P_{meh.r.n}$	15544,46	138340,1
$P_{e1} = q_1 R_1 I_n^2$	876,15	5102,32
$P_c = P_{1n} - P_{e1} - P_{em.n}$	361,9	985,11
$R_{00} = P_c / (q_1 I^2_{00})$	1,967	0,417
$R_0 = R_{00} - R_1$	1,6	0,336
$P_{e2} = q_1 R'_2 I'^2_{2n}$	377,3	4620,98
$\sum P = P_{e1} + P_c + P_{e2} + P_{dop} + P_{meh}$	1816,74	13236,9
$I_{00a} \approx P_c / (q_1 U_1)$	0,548	0,864
$I_{00p} = \sqrt{I^2_{00} - I^2_{00.a}}$	7.812	28,037

2.1 Underlined Values were Used in Work Simulation of Machines ZK 160L-4 *u* ZKI 315M-6)

Values of the error shown in Table 4 determined according to formula (1), are far smaller than the values determined according to formulas from Table 3. So for the resistance values R_1 and R'_2 of motor ZK 160L-4 and R_1, R_2', R_0 of ZKI 315M-6 errors were increased by 5%, and for reactance X, X_2', R_0, X_0 for ZK 160L-4 and X_1, X_2', X_0 for ZKI 315M-6 the errors fall within the interval 10-17% which is acceptable in technical calculations.

During the calculations of values in Table 4 following formulas were used [15]:

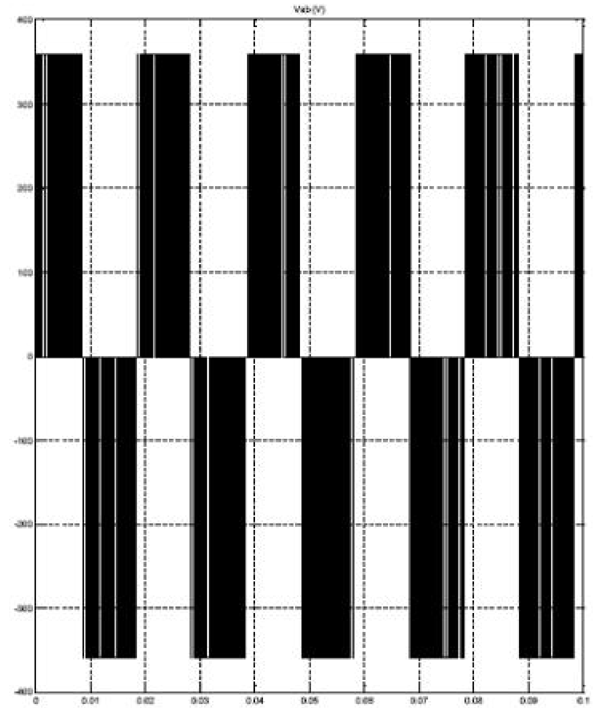
$n = n_1(1-s)$, $X''_2 = \sigma_1 X_1 + \sigma_1^2 X'_2 = X''_k$, $Z''_2 = \sqrt{R''^2_2 + X''^2_k}$, $I''_2 \approx U_1 / Z''_2$,

$I''_2 = \sigma_1 I''_2$, $\cos\varphi''_2 = R''_2 / Z''_2$, $\sin\varphi''_2 = X''_k / Z''_2$ $I''_{2a} = I''_2 \cos\varphi''_2$, $I''_{2p} = I''_2 \sin\varphi''_2$,

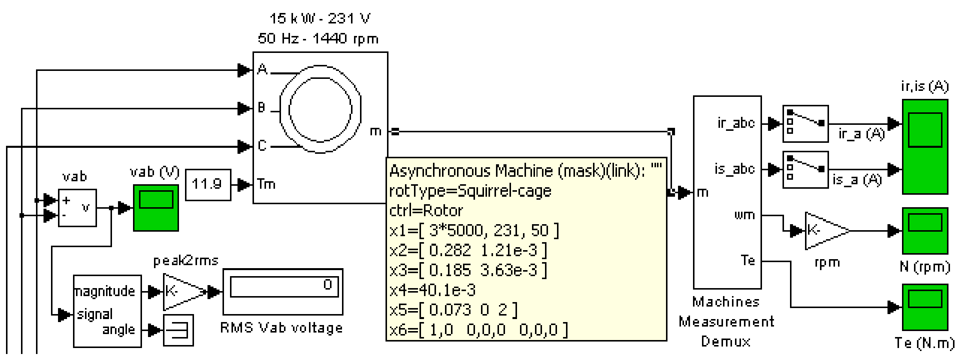
$I_{1p} = I_{00p} + I''_{2p}$, $I_{1a} = I_{00a} + I''_{2a}$, $I_1 = \sqrt{I^2_{1a} + I^2_{1p}}$ $\cos\varphi = I_{1a} / I_1$, $P_1 = q_1 U_1 I_{1a}$,

$P_2 = P_1 - \sum P$, $P_{e1} = q_1 R_1 I_1^2$ $P_{e2} = q_1 R'_2 I'^2_2$, $P_{dop} = 0{,}005 P_{1n}$, $P_{meh} = 0{,}007 P_{1n}$,

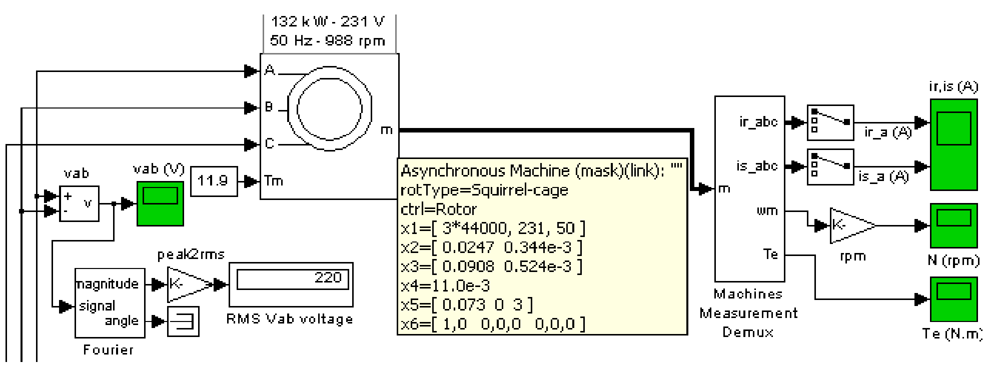
$\sum P = P_{e1} + P_c + P_{e2} + P_{dop} + P_{meh}$, $P_{em} = P_{e2} / s;\ M = 60 P_{em} / 2\pi n_1$.



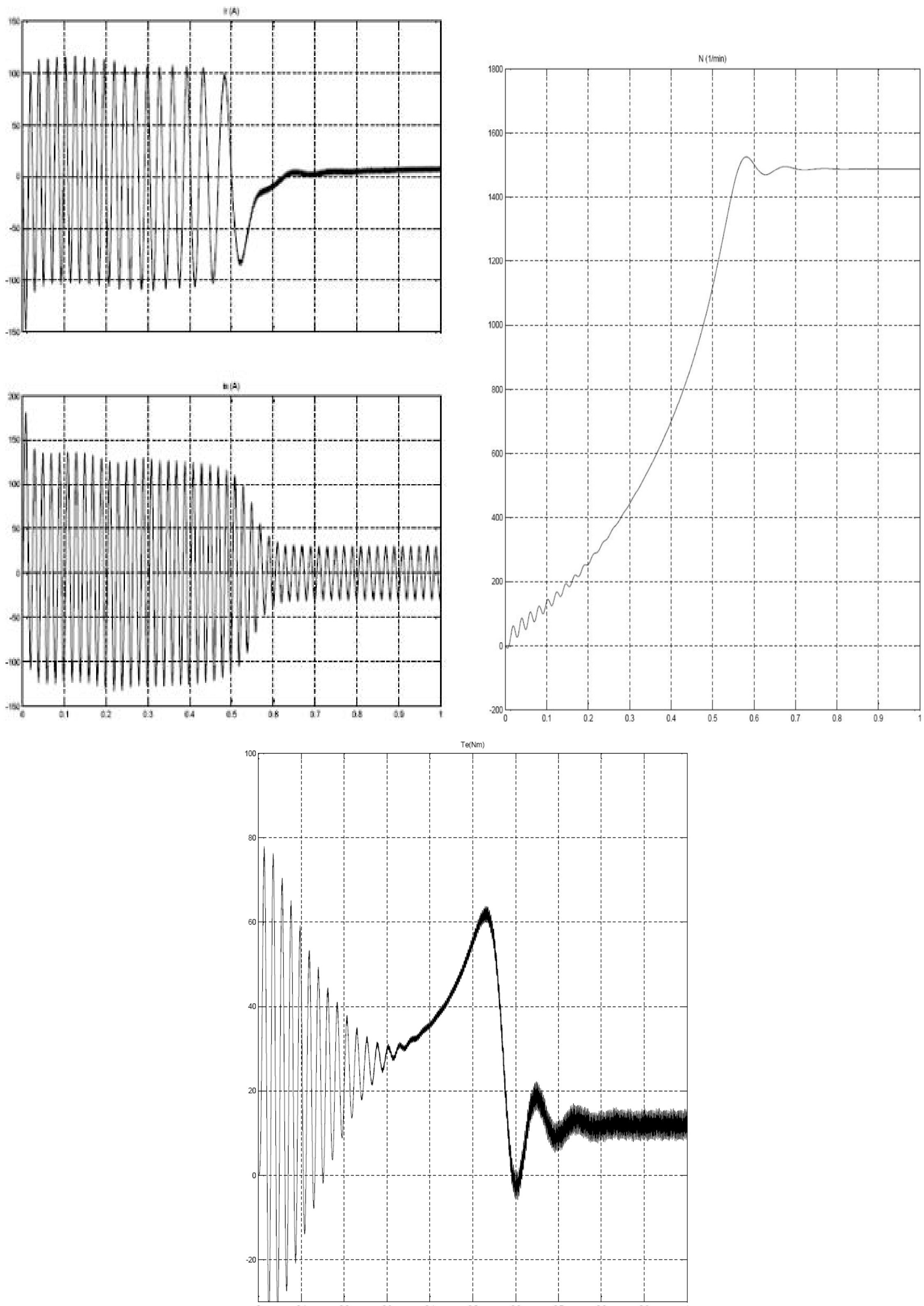
Picture 2.a. Rectangle shape of power supply voltage



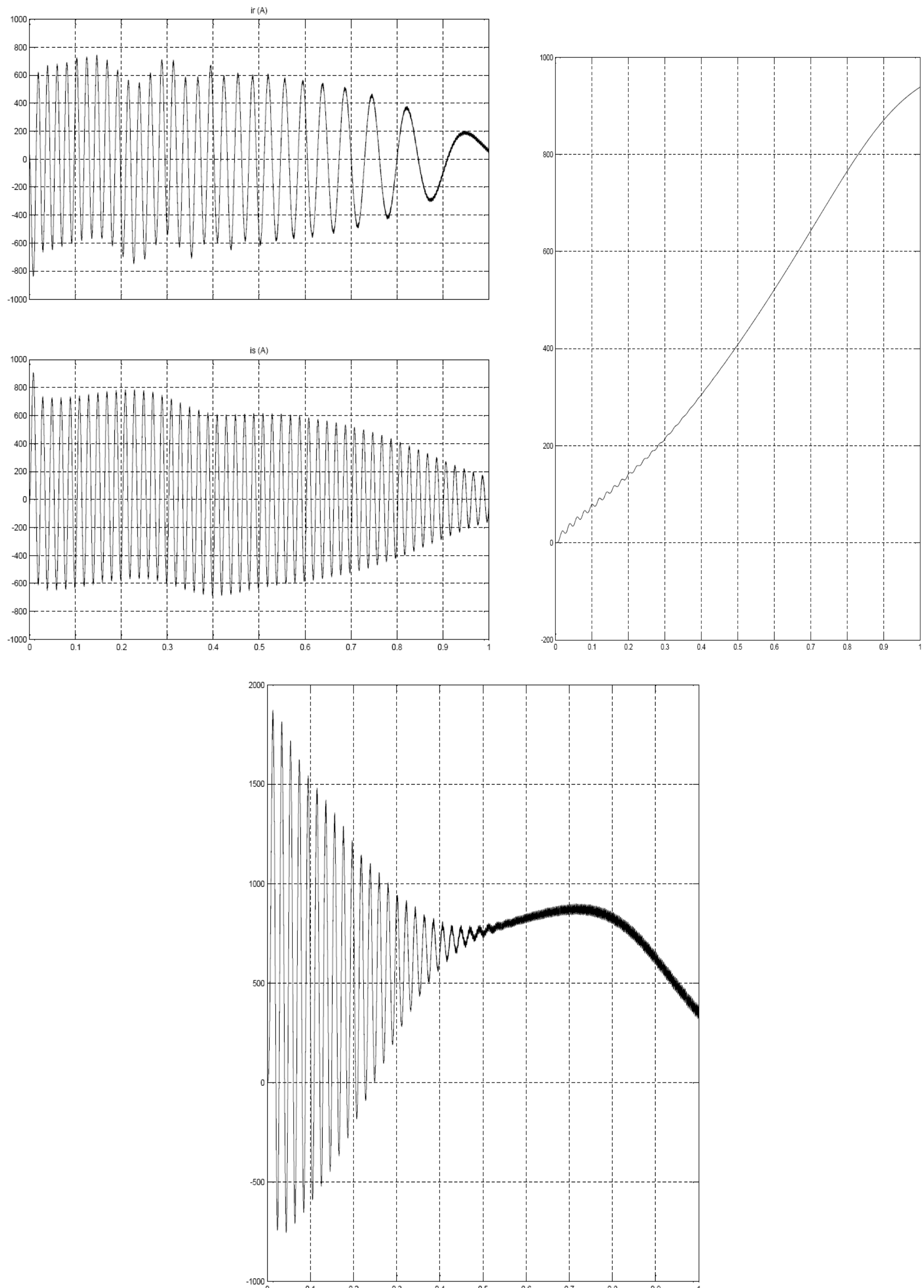
Picture 2.b. Schema for simulation of work and obtaining characteristics of the machine ZK 160L-4



Picture 2.c. Schema for simulation of work and obtaining characteristics of the machine ZKI 315M-6



Picture 3. Working characteristics of ZK 160L-4



Picture 4. Working characteristics of ZKI 315M-6

A new simulation algorithm has been created by using adapted mathematical model. The advantage of the implementation of computer simulation is in the fact that it is completely harmless for the machine, as well as for the staff, and the results obtained are in accordance with reality and the process itself. Obtained mathematical model of the machine can be used for the analysis of its work and for the control synthesis, and from the very model complex algorithms can be developed for electrical machines control, vector control and momentum control.

This model simulates work of machine quite accurately, it has special advantages, and it enables detailed view in all the components of the model and the program, as well as entering different variations in order to analyze the changes. According to MATLAB 6.5 software for rectangle shape of power supply voltage, Picture 2.a, for machines ZK 160L-4 Picture 2.b and ZKI 315M-6 Picture 2.c work has been simulated and characteristics which are obtained are Picture 3 and Picture 4.

3. CONCLUSION

While calculating short circuits in the grid, when the influence of asynchronous motors is important, it is not necessary to determine all the resistance values while following formulas from Table 3. It is enough to determine only values of Z_e and Z_p motors.

If the calculation of working characteristics of motor is necessary, parameters of equivalent circuit should be determined by using formulas from Table 4. As the result of the simulation it is determined that the difference between appropriate values *A* and *A*p for both machines is insignificant and is not beyond 5%. This is why working characteristics calculated according to values of coordinates A and A_p are practically the same. Working characteristics of ZK 160L-4 and ZKI 315M-6 obtained by using parameters R_1, X_1, $R`_2$, $X`_2$, R_0, X_0 and determined only by the formulas from Table 4 are shown in Pictures 2 and 3.

It is demonstrated in this way that determination of resistance in equivalent circuit according to formulas from Table 4 is suitable for calculations of working characteristics of asynchronous machines.

Obtained mathematical model of the machine can be used for the analysis of its work and for the control synthesis, and from the very model complex algorithms can be developed for electrical machines control, vector control and momentum control.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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